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THESIS

CONTRIBUTION TO THE AUTOMATIC EXTRACTION OF LINEAR STRUCTURES FROM SATELLITE IMAGERY

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THESIS

CONTRIBUTION TO THE AUTOMATIC EXTRACTION OF LINEAR STRUCTURES FROM SATELLITE IMAGERY

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INTRODUCTION

The diversity and the quality of the images provided by satellite imagery is of great interest to remote sensing centers and users. The applications include: crop management, geology, mineral or oil prospecting, hydrology, oceanography, mapping, etc. The analytical methods are numerous: statistical, spectral and morphological analysis.

Data gathering and its update for geography and mapping is one of the most difficult tasks to undertake at present. The present study addresses this problem. Its goal is to provide a semi-automatic and an automatic extraction of linear structures from satellite imagery. SPOT images are of interest due to their suitability for the extraction of highways, main roads, railway lines, rivers and seashores. SEASAT images can be used to extract geological lineaments.

Chapter I presents the results of the mathematical morphology processing of satellite imagery. In Chapter II, we present the results of the standard deviation method improved by the use of mathematical morphology functions.

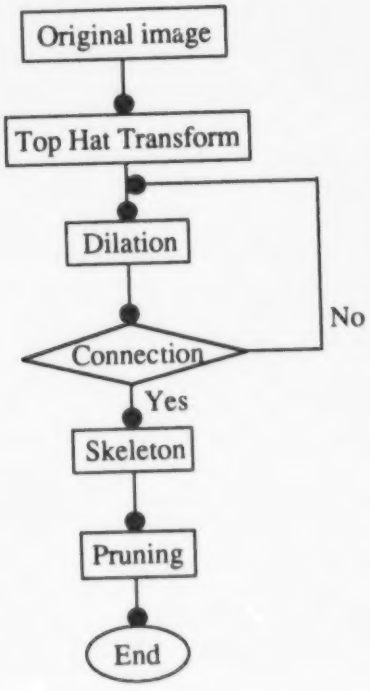
Following a discussion of the limitations of these methods, the following chapters present a method based on graph theory used to detect linear structures. Chapter III includes the theoretical aspect of the graph theory and illustrates the fact that searching for a linear structure in an image is similar to minimizing a certain cost function. Chapter IV presents the results of a semi-automated process. Chapter V discusses the results of an automated process suitable for the detection of linear structures from satellite imagery.

The general conclusion deals with processes likely to be tested to improve the method.

I. MATHEMATICAL MORPHOLOGY APPLICATION

1.0 INTRODUCTION

The application of mathematical morphology to satellite data image analysis seems to be efficient (Destival 1986, Berthod 1987, Merghoub 1985). We applied the classic mathematical morphology transforms, as shown by the flow chart below:



- the top hat transform highlights peaks and valleys of the gray-level function
- the dilation connections pixels belonging to a given structure
- the skeleton transform gives the median axis for each structure
- the opening removes small endpoints

For more information about mathematical morphology, please consult J. SERRA (1982).

2.0 RESULTS AND COMMENTS

The results achieved on the test image of New Caledonia (simulation SPOT-XF) are not satisfactory.

The top hat transform (structuring element of size 2 and threshold of 14 for the contrast) resulted in the detection of only the most obvious structures. The others are either hidden by false detections or cut by the threshold (Figure I.2.a).

The dilation transformation reconnects the shortest sections. The dilation function will yield false information if repeated too many times (Figure I.2.b).

The skeleton function (Figure I.2.c) allows the user to visualize contours in the same way but at a reduced width (one pixel). A major disadvantage of this technique is that it further separates section discontinuities.

Methods based on mathematical morphology (Destival 1986, Berthod 1987), applied to the test image, did not give good results. This may be related to the complex nature of the image (different structures). The context of a river is not the same as the one of a main road. As the mathematical morphology functions are processed on the whole image, some structures can be detected and others removed. But if only one structure is selected, mathematical morphology will be useful in ensuring the continuity of the isolation of the seeked structure.

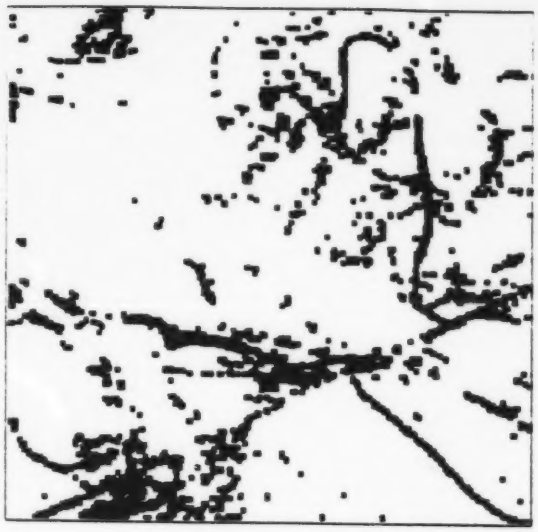
Dilation, skeleton and "pruning", functions used to remove small sections, could be efficient for this type of application. A major problem is that the user does not know in advance how many dilations and "prunings" are required to clean up the image.

3.0 CONCLUSION

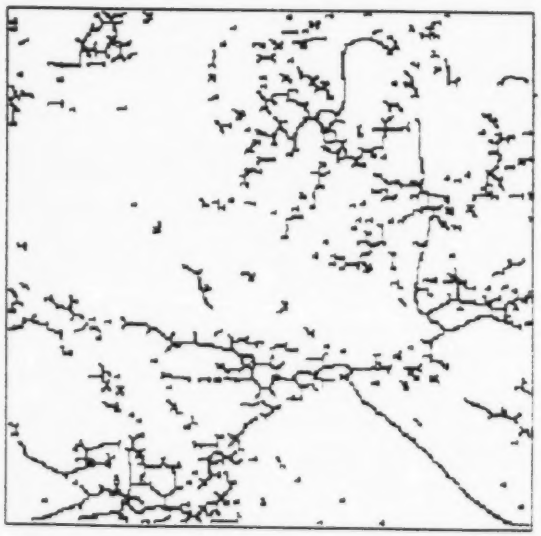
In conclusion, mathematical morphology cannot by itself provide a complete extraction of communication networks in satellite images. It can however, be used to either pre-process an image or fine tune the results of a process using another approach.

Figure I.1 Original image (New Caledonia XP)

a) Top Hat transform
Size=2, Threshold=14



b) Dilation of image a)



c) Skeleton of image b)

Figure I.2 Detection using morphology transforms

II. DETECTION BY A STANDARD DEVIATION METHOD

1.0 INTRODUCTION

Within satellite image data one notes a variety of information: fields, forests, urban zones, communication network ... The goal of this study is linear structure extraction: the use of a criteria based on standard deviation allows the detection of zones having a discontinuity, rich in information about contours.

We processed a standard deviation calculus in a window (n,n) centered on the pixel, followed by a threshold using this value to highlight zones where the standard deviation was high. Only pixels whose standard deviation value is over the threshold are kept inside the analysis window. The standard deviation is given by the following expression:

$$STD = \left[\sum_{u \in D} \frac{(X(m) - M)^2}{n^2} \right] SUP1/2$$

with M: mean of the window
X(u): grey-level of the pixel u inside the window D
N: size of the window (n=3)

2.0 RESULTS AND COMMENTS

Thresholding the standard deviation image, using the standard deviation histogram, we obtained the Figure II.1 where roads and part of the river (in a very contrasted region) are well detected. However, it was difficult to highlight a road in a low contrasted region.

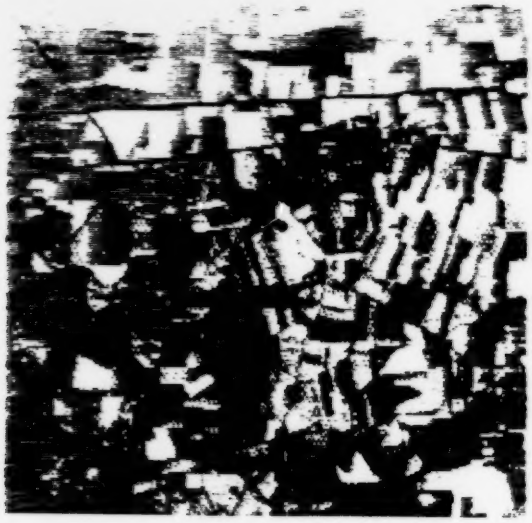
The advantage of thresholding, using standard deviation, is the ability to highlight linear structures with low time processing (CPU = 38 seconds on a MicroVax II).

This method is efficient when the background of the image is more or less uniform (when field edges are smooth). When the fields have sharp transitions, their detection is unavoidable.

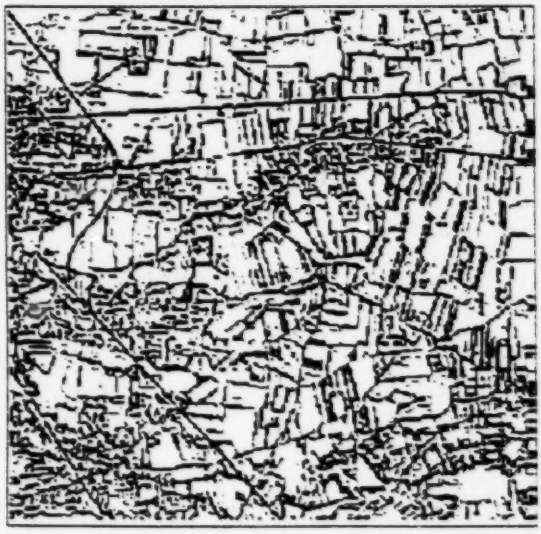
Results are illustrated based on a standard deviation segmentation on two 256 x 256 SPOT images from La Rochelle, France (date: 30.4.86, XS3-20m, K=35, J=257 in the SPOT image reference system), For this process, each central point of the window was removed if the standard deviation was lower than the window mean (Maitre 1978). The mean allows the fine tuning of the result and the rejection of neighbourhood contours.

The communication network and the field edges are shown in Figure II.2.b. A higher threshold will not allow the elimination of field edges, nor the isolation of the entire communication network without modifying the seeked information (i.e. Figure II.2.c).

Figure II.1 Detection using standard deviation
Threshold = 8, n = 3



a) Original Image (La Rochelle XS3)



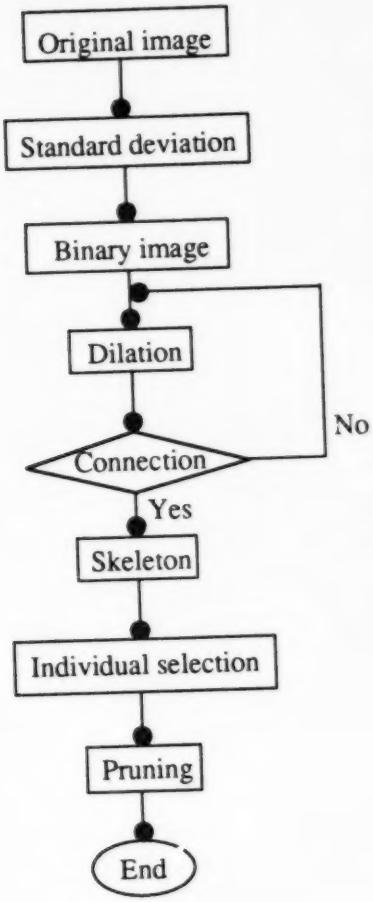
b) Segmented image using standard deviation
Threshold = 3, n = 3

c) Segmented image using standard deviation
Threshold = 8, n = 3

Figure II.2 Segmentation, using standard deviation, of an image having a high density of square structures (fields)

3.0 IMPROVEMENTS OF THE RESULTS BY MATHEMATICAL MORPHOLOGY

Combining the two approaches, we can process the image according to the following diagram:



Dilation connects some components of the main and secondary roads. To avoid square formation, the number of dilations must be limited. To eliminate false detections (isolated structures), we selectively choose the structures. We eliminate sections of a length shorter than a given threshold (L=15 pixels). The result is shown in Figure II.3.

4.0 CONCLUSION

This method of using standard deviation can detect the general communication network if the image does not include contracted fields. Despite the fact that mathematical morphology has improved the process, the final results are still unsuitable. Development of a new method to detect and follow contours is the only way to fill the discontinuities present in the image.

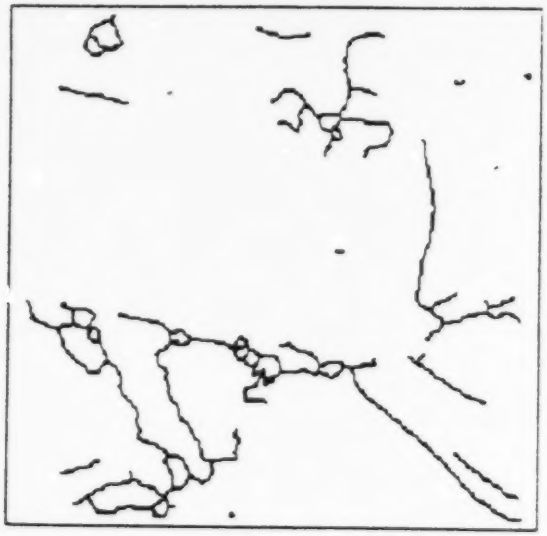


Figure II.3 "Pruned" skeleton

III. EDGE DETECTION BY OPTIMIZING A PATH IN A TREE DIAGRAM

1.0 INTRODUCTION

In this chapter we will show how seeking a linear structure in an image is like looking for a certain path in a tree diagram.

2.0 TREE DIAGRAM OF ELEMENTARY EDGES

X(s) is the grey level of the pixel s(s=(1,1),(1,2),(1,3),...).
An image is:

$$\{X(s),\ s \in \mathbb{N}^2\}$$

You associate a tree diagram to the image. A node of the tree diagram is an elementary edge that is defined by a vector separating two pixels next to each other.

The node x is defined by the vector A(x)B(x) or by the couple $(s,t)(\neq(t,s))$.

Definition: the node y is **the successor** of the node x if
$A(y) = B(x)$ and $B(y) \neq A(x)$

Therefore, each node has three possible successors y_1, y_2, y_3.

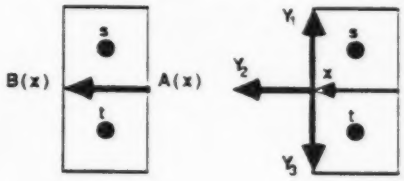
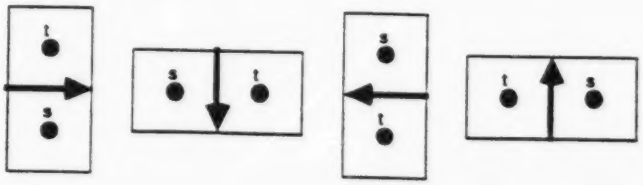


Figure II.4

The direction given to an elementary edge is coded by a figure from 1 to 4.



direction 1 2 3 4

Figure II.5

Definition: a **path connecting two nodes** a and b is a vector of nodes $G_n = (x_1,x_2,x_3,...,x_n)$ so that $(a=x_1)$ and $(b=x_n)$ and x_{i+1} is the successor of $(x_i, 0 < i < n)$.
For every G_n, you calculate a cost $C(G_n)$ and you choose to minimize the cost. The choice of a given cost reflects certain properties like regularity, curviness...

Example: let's take $C_1(G_n)$ and $C_2(G_n)$, two costs defined recursively.

$C_1(G_n) = C_1(G_{n-1}) + C(x_n)$

where $G_n = (x_1,...,x_n)$ and $C(x_n) = Sup(0, M + X(u) + X(v) - X(s) - X(t))$ measures the contract between two zones separated by the elementary edge x_n. (See Figure II.6).

and $M = Sup(|X(1) - X(m)|, m \in (s,t,u,v))$

$C_1(G_n)$ represents the contrast between x_1 and x_n.

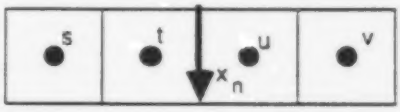


Figure II.6

$C_2(G_n) = C_2(G_{n-1}) + wc.\Theta_n$

where Θ_n is the angle between the two vectors $A_{n-2k}B_{n-k}$ and $A_{n+1-k}B_n$. It measures the curviness of the two underpaths, each made of "k" elementary edges; "wc" is a weighted coefficient.

Example: with k=5

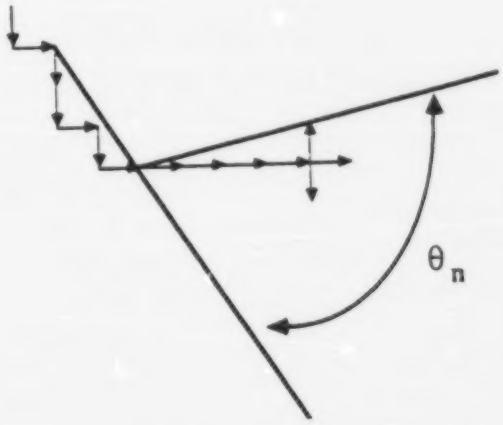


Figure II.7

This cost represents the curviness of a path.
The global cost of a path can then be
$C_1(G_n)+C_2(G_n)=C(G_n)$

3.0 A SEEKING METHOD WITH A "UNIFORM" COST

3.1 Notation

$C(G_i)$ is the cost of a path between x_1 and x_i.

$C(G_{ij})$ is the cost of a path between the node x_i and one of its successors x_j.

A handle is associated with every node.

A-list: list of the nodes not already processed.

B-list: list of the nodes already processed.

3.2 Algorithm

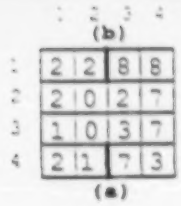
Step 1: put the initial node x_1 onto the A-list.
Step 2: if the A-list is empty, failure: no solution exists.
Step 3: transfer from A-list to B-list the node x_i that has the smallest cost $C(G_i)$.
Step 4: if the node x_i is the final node, then the path minimizing the cost is found. This path is obtained by covering the tree diagram backwards from the final node to the initial node considering the handles created at Step 6; otherwise go to Step 5.
Step 5: you consider the node x_i. If it has no successor, go to Step 2.
Step 6: for each successor x_j of the mode x_i,

- calculate $C(G_j) = C(G_{ij}) + C(G_i)$.
- put x_j in the A-list, if it doesn't already belong to the A-list or the B-list.
- if the successor x_j is in the A-list or in the B-list, update the cost $C'(Gj) = \min(C(G_j), C(G_i)+C(G_{ij}))$.
- if the $C'(G_j) < C(G_j)$ and $x_j \in$ A-list, then x_j is transferred from A-list to B-list. All the handles of the successors x_j, whose cost $C(G_j)$ has been reduced, point out the node x_i.

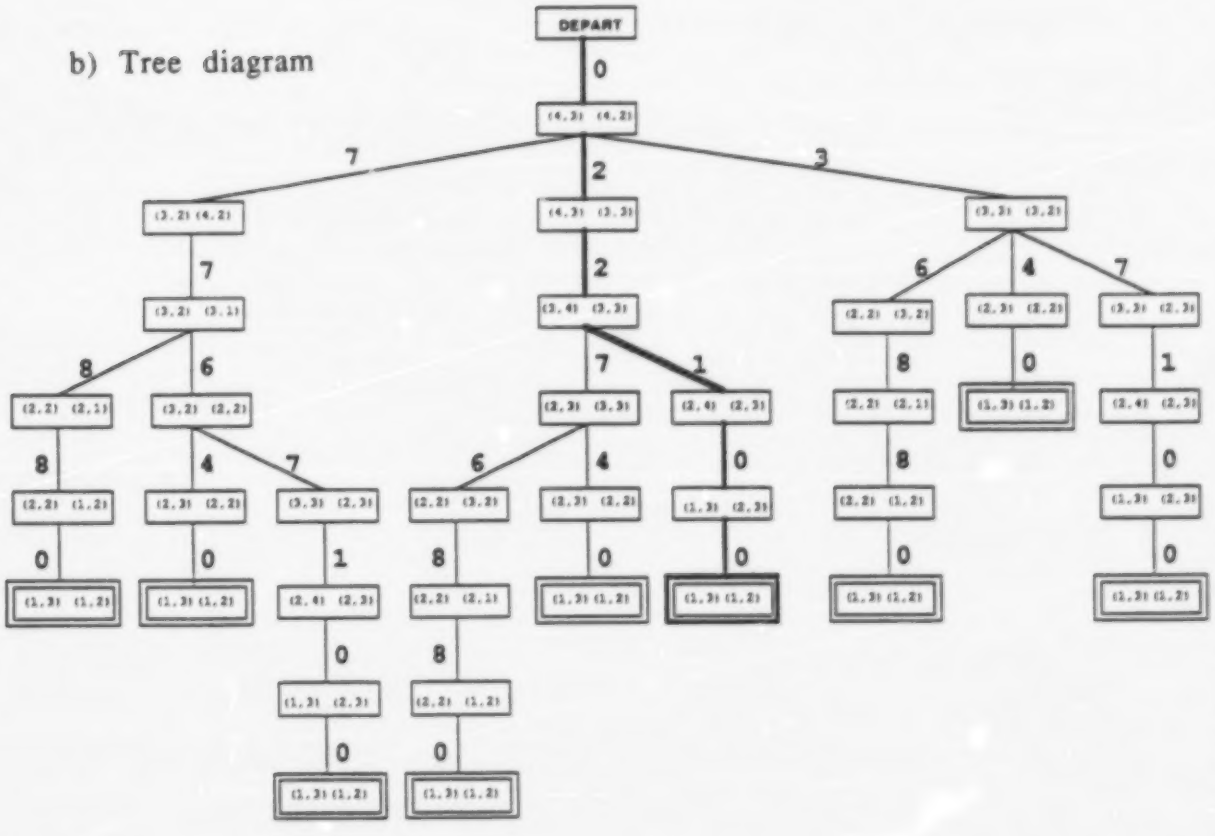
Step 7: go to Step 2.

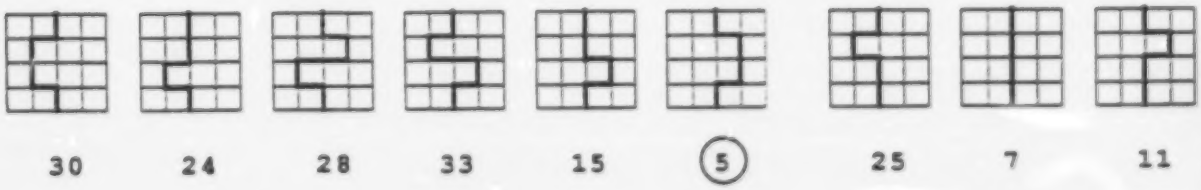
The first example is based on the calculation of a cost that does not include curviness ($C_2=0$, $C=C_1$). The path chosen is the one that minimizes the cost (i.e. minimize the contrast). If you add the curviness cost ($C_2=1$, for instance, if there is a change of +/- 90° in the direction), you will get a different edge (second example).

a) Image with contour



b) Tree diagram

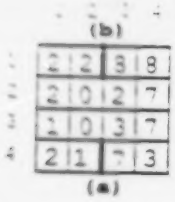




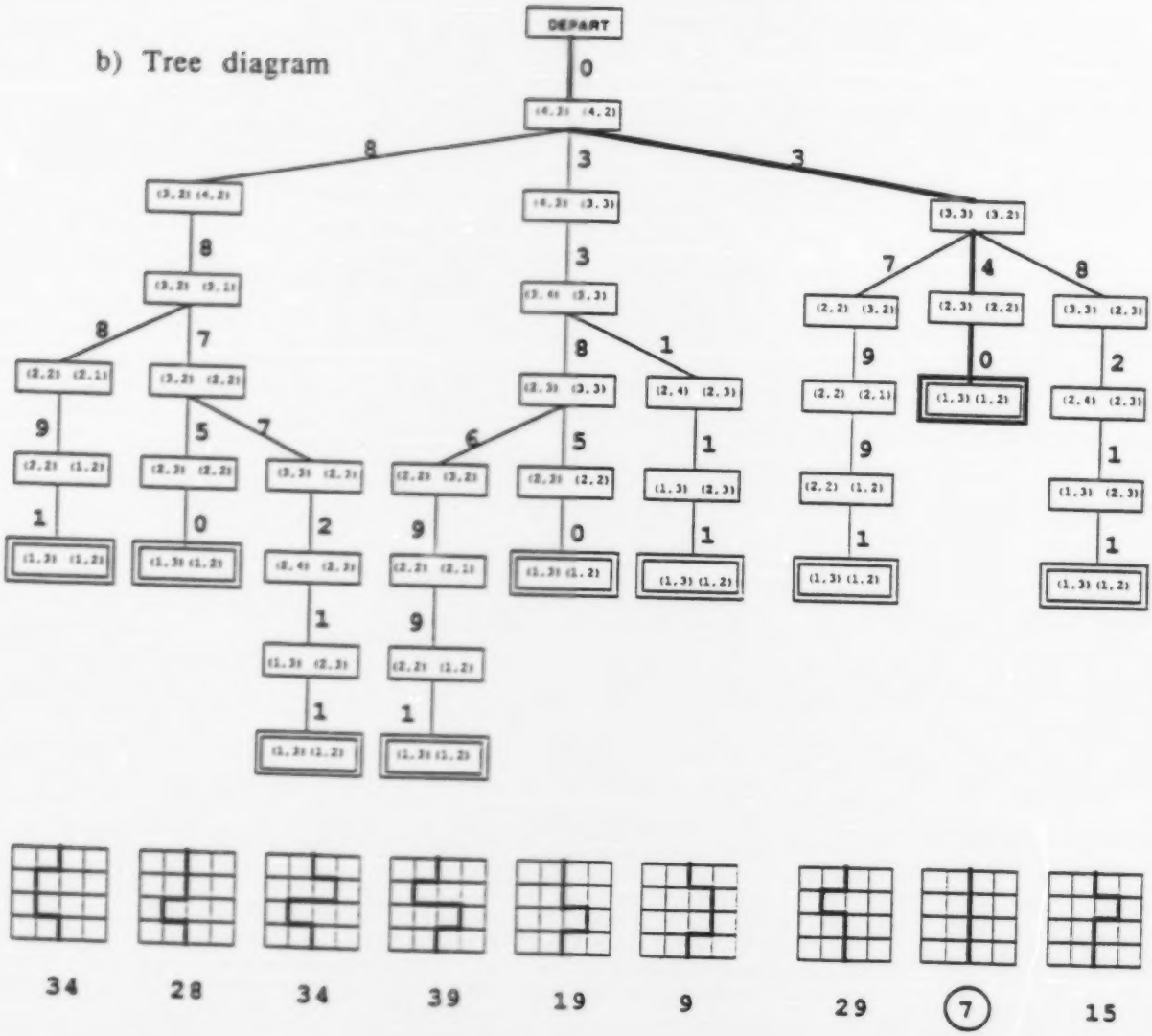
c) Cost of the different paths

Figure II.8: C = C_1

a) Image with contour



b) Tree diagram


DEPART
0
8
3
3
8
3
8
7
7
4
8
9
5
7
6
5
1
9
0
2
1
9
1
2
1
1
9
1
1
1

IV. APPLICATIONS FOR SEMI-AUTOMATIC LINEAR STRUCTURE EXTRACTIONS

1.0 EDGE DETECTION BY OPTIMIZING A PATH IN A GRAPH: PRINCIPLE

The seeking algorithm of a minimized cost network generates, step-by-step, the graph from a departure node (a) until it reaches the arrival node (b). The path $C(G_n) = C(G_{n-1}) + C(x_n) + wc.\Theta_n$.

where $C(x_n)$ measures the contrast between two zones divided by the elementary edge "n".

"$wc.\Theta_n$" is the cost related to the curviness of the two underpaths, each of them made of "k" elementary edges.

The departure and arrival state (position, direction) of the structure one wishes to extract are predetermined interactively.

One may wish to extract a given structure (highways, roads, railways, seashores, geological lineament) from satellite imagery (SPOT SEASAT).

To do so, one will have to input the algorithm with the parameters required for the calculation of the cost function and the seeking method elaboration.

These parameters are:

- •a Departure position
- •diri Departure direction
- •Sa Number of pixels in the departure zone
- • Weight coefficient of the curviness cost
- •K Length of the curviness evaluation path made of two underpath of elementary edges $K=2k\pm1$
- •p Recursivity in the tree levels: a node located in the "p" past tree levels will be candidate to be developed
- •M Maximum gray-level difference between two neighbouring pixels
- •b Arrival position
- •dirf Arrival direction
- •Sb Number of pixels in the arrival zone

N.B.: The parameter choice has a great influence upon the behaviour of the algorithm. These parameters will have to be coherent between each other to avoid false seeking paths.

When the "seeked structure" is located in a rough environment (intersection with crossroads or another structure), the detection of the seeked structure is done step-by-step. The final path passes through intermediate control points, chosen in advance.

2.0 APPLICATIONS FOR A SEMI-AUTOMATIC EXTRACTION

The goal is to respond to photointerpreter and mapping needs, extracting specific information related to their applications. The methodology will allow them to extract linear structure in a minimum time without any prior knowledge of image processing.

2.1 Mapping Application

Extraction of Communication Networks

The first application of the algorithm was done on an image of New Caledonia (SPOT-XP simulation) and was used to extract some communication lines illustrated by the following figures:

- original image (Figure IV.1.a)
- extraction of an important road (Figure IV.1.b)
- extraction of rivers (Figure IV.1.c)
- extraction of smaller roads (Figure IV.1.d)
- image of the nodes explored for the seeking
- superposition of the entire extracted network with the original image (Figure IV.2.b)

The results show the algorithm is, in each case, capable of detecting the seeked structures, that are not easily detected by current methods.

Note the results of the segmentation done by the standard deviation segmentation (Figure IV.2.c) and the results of the seeking optimum path algorithm for three different zones (road, secondary road, river) (Figure IV.2.b). The extraction of the main road is particularly difficult.

A second illustration shows part of the extracted communication network overlapped with the original (Figure IV.3.a), compared to the result of a visual interpretation done by a photointerpreter. It should be noted that semi-automatic and manual methods are similar for extracting information in an urban area (main road case).

a) Original image

b) main road

a=(246,144), diri=3, Sa=1, K=10, p=3, M=20, wc=40,
b=(191,175), dirf=3, Sb=1
a=(191,175), diri=3,Sa=1, K=10, p=5, M=5, wc=40,
b=(86,237), dirf=2, Sb=1

c) rivers

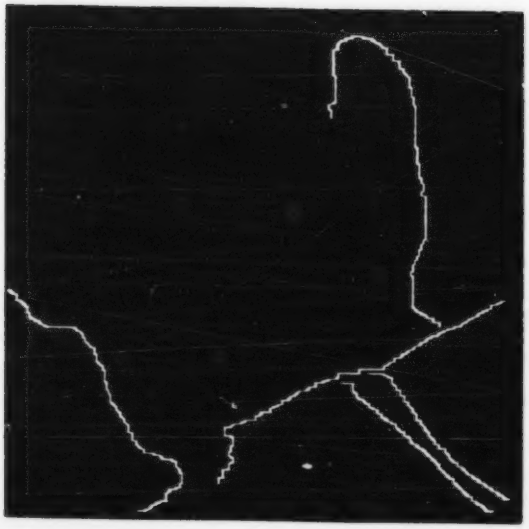
a=(3,143), diri=1, Sa=1, K=10, p=3, M=50, wc=40,
b=(68,251), dirf=3, Sb=1
a=(181,181), diri=1, Sa=2, K=10, p=3, M=40, wc=40
b=(248,243), dirf=1, Sb=2

d) secondary roads

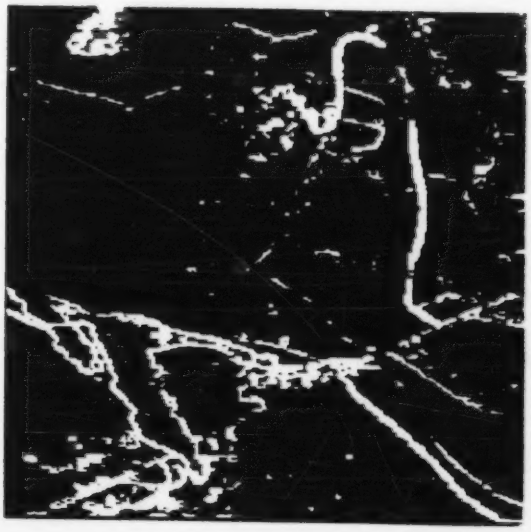
a=(162,54), diri=4, Sa=1, K=10, p=3, M=30, wc=40,
b=(215,157), dirf=2, Sb=1
a=(168,187), diri=3, Sa=1, K=10, p=3, M=30, wc=40
b=(240,250), dirf=1, Sb=1

Figure IV.1 Communication network extracted by a semi-automatic approach

a) Image of the nodes explored by the seeking method

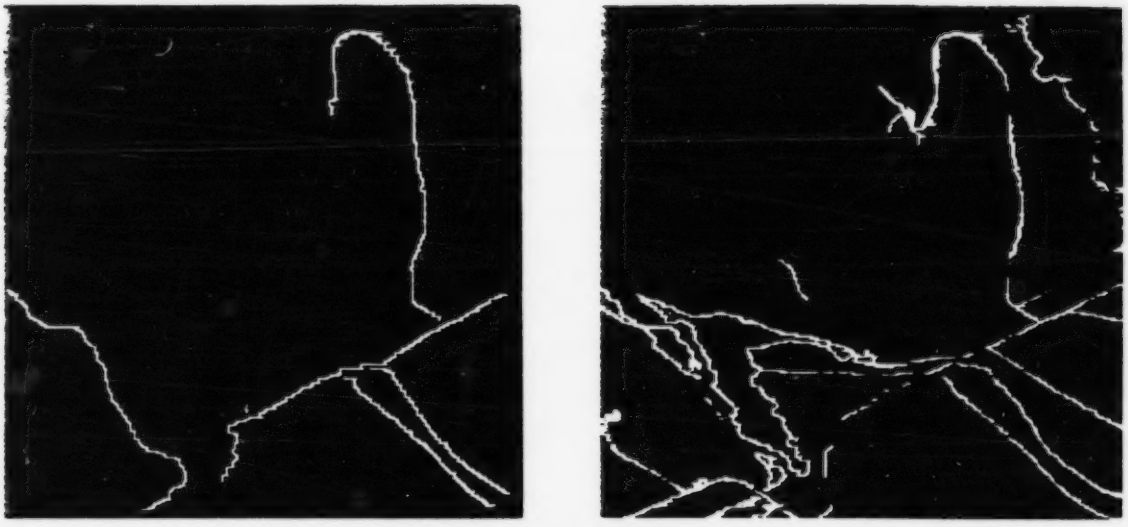


b) Superposition of the entire extracted network with the original image



c) Result of the standard deviation segmentation

Figure IV.2



a) Part of the network extracted by a semi-automatic approach, superimposed on the original

b) Photointerpreted network superimposed to the original

Figure IV.3

Other applications such as seeking a given structure, were also done on smaller images (256 x 256) of a SPOT scene of La Rochelle (France) (date: 30.4.86, XS3-20m, K=35-J=257 in the SPOT image reference system).

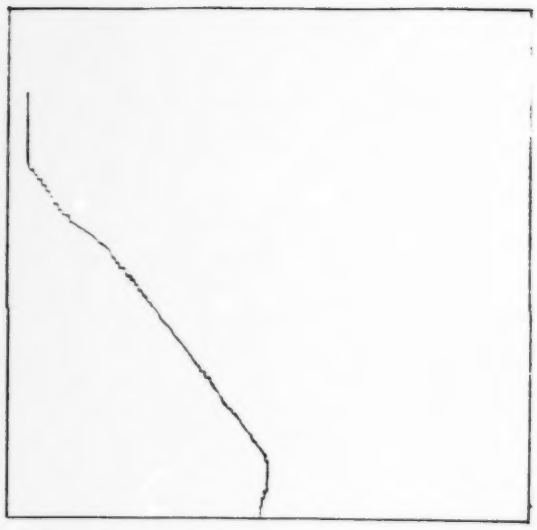
The results obtained by this semi-automatic approach are displayed by the following figures:

- original images (Figures IV.4.a, IV.5.a)
- extraction of a highway (Figures IV.4.b, IV.5.b)
- extraction of railway line (Figure IV.4.c)
- extraction of road (Figure IV.5.c)
- overlapping of the network with the original image (Figure IV.4.d, IV.5.d)

The overlapping of the network and the original image indicates that the three "seeked structures" are extracted (highway, road, railway line) accurately, with the exception of the main road (Figure IV.5.c), which displays a slight deviation in the middle due to a nearby crossroads (i.e. extracted from the communication network map of La Rochelle, Figure IV.5.bis).

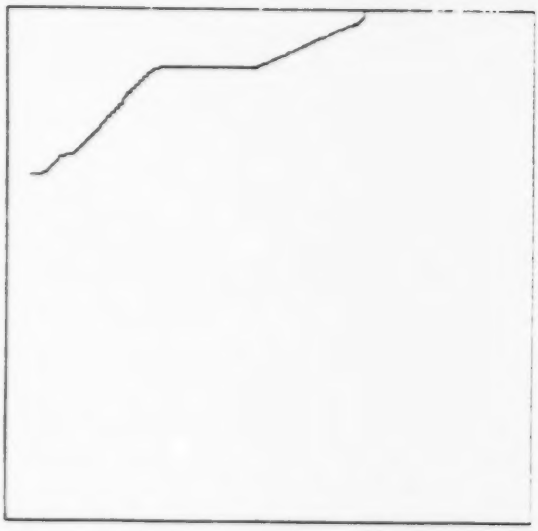
N.B. The results of IV.4.b and IV.5.b are processed in two steps, with one intermediate control point.

a) Original image



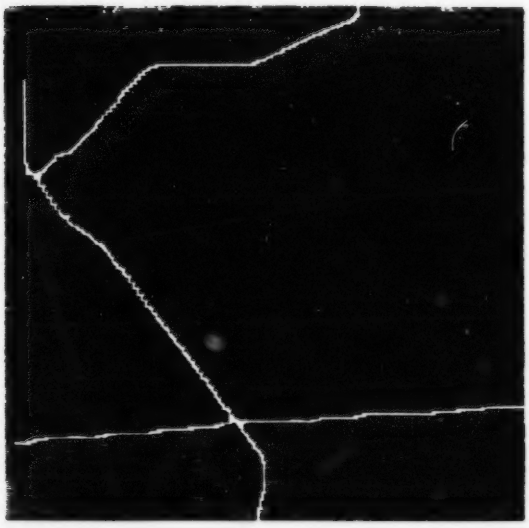
b) Extraction of a highway

a=(123,254), diri=4, Sa=3, K=10, p=3, M=100, wc=100,
b=(29,105), dirf=4, Sb=1
a=(29,104), diri=4, Sa=1, K=10, p=3, M=100, wc=100
b=(8,38), dirf=4, Sb=3



c) Extraction of a railway line

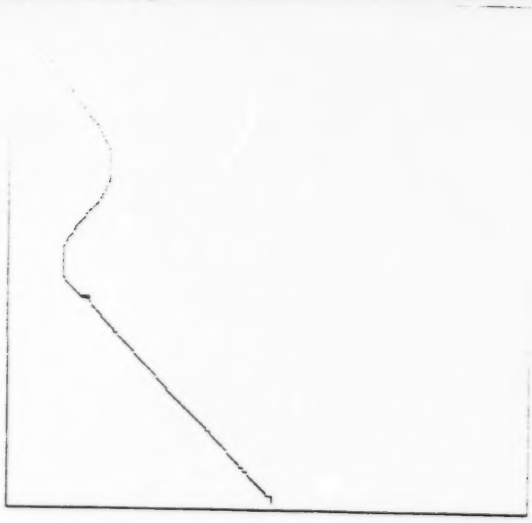
a=(176,1), diri=2, Sa=1, K=8, p=3, M=120, wc=70,
b=(12,87), dirf=3, Sb=1



d)Superimposed extracted network on the original image

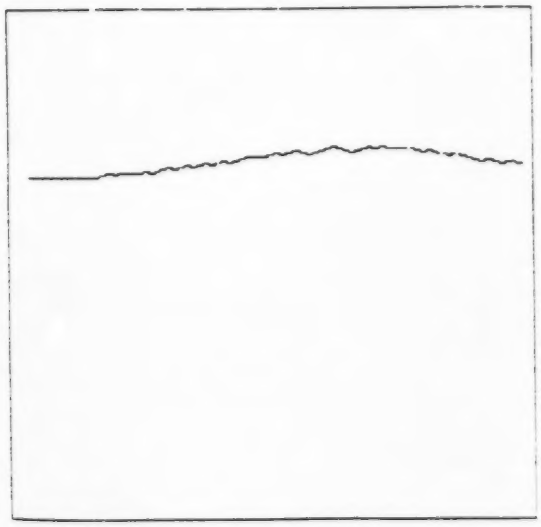
Figure IV.4 Network extracted by the semi automatic approach

a) Original image



b) Extraction of a highway

a=(7,10), diri=2, Sa=3, K=5, p=2, M=110, wc=85,
b=(42,152), dirf=1, Sb=4
a=(131,252), diri=4, Sa=3, K=8, p=2, M=100, wc=110,
b=(43,152), dirf=4, Sb=4



c) Extraction of a main road

a=(11,83), diri=1, Sa=3, K=8, p=3, M=50, wc=110,
b=(250,77), dirf=1, Sb=4

d)Superimposed extracted network on the original image

Figure IV.5 Network extracted by the semi-automatic approach

2.2 Geological Application for Lineament Extraction

With the collaboration of CARTEL (Centre d'Application et de Recherche en Teledetection de l'Universite de Sherbrooke), a study for extraction and analysis of geological lineaments, was conducted by J. Daoust in the image analysis laboratory of the center. The object of this study was to test the semi-automatic approach of structure extraction in different fields that were previously discussed. These lineaments were associated with structural elements (i.e. faults) and appeared as linear and curvilinear elements (Deslandes 1988).

The study processed a Seasat image of a zone included in the Stokes mounts, located 40 km north-east of Sherbrooke, Quebec, Canada. This site is of a great interest to mining companies. Satellite data are abundant and the area was previously analyzed for lineament identification (Deslandes 1988, Daoust 1988).

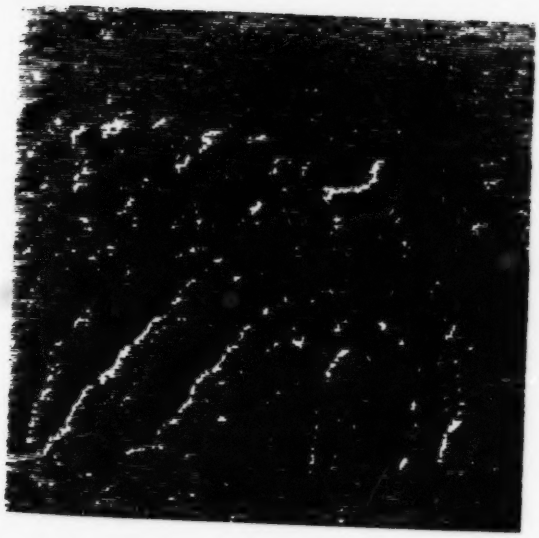
The results reached in this rough terrain are interesting (i.e. Figures IV.6.a and IV.6.b). Generalization of this process leads to the automatic extraction of all the lineaments. This automatic extraction is presented in Part II of this chapter. This is of a great interest to the mining companies, which are looking for automated processes to map lineaments in order to define zones with a high mineralization potential. A recent paper of J. Wang et al (1989) deals with this field. Their study was based on a graph seeking method. However, it would be difficult to totally automate this method for lineament detection.

At this time lineaments are only identified by manual interpretation. Two or three photointerpreters do a visual extraction of lineaments, and then combine the results, keeping only the elements that are in common with the three photo-extractions. The study of J. Daoust (1989) suggests an automatic extraction method based on directional filtering and morphology transforms.

The final image from J. Daoust (Figure IV.7.a) is compared to the results of two lineament detections by the semi-automatic approach in Figure IV.7.b. Although the geological validity of the results are not entirely established, the comparison between the two indicates that the lineament detected by directional filtering are broken up and the semi-automated lineaments are not.

3.0 CONCLUSION

Chapter IV includes a semi-automatic approach to extract linear structures, an interactive tool available for specialists. This method allows them to efficiently extract the required information for regional planning and map updating.

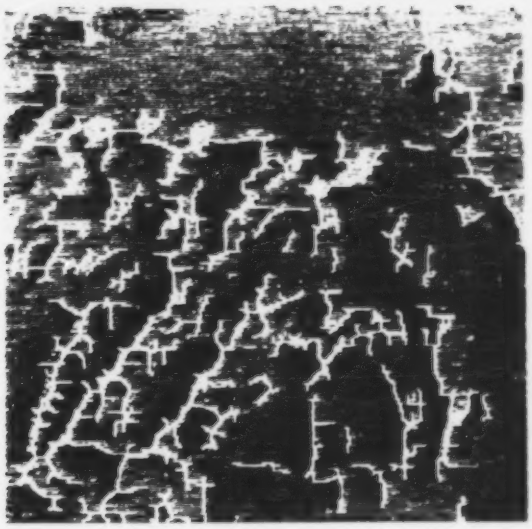


a) Original image (SEASAT)

b) Extracted lineaments superimposed on the original image

a=(195,227), diri=4, Sa=3, K=8, p=5, M=200, wc=140,
b=(152,214), dirf=2, Sb=2
a=(12,229), diri=1, Sa=3, K=4, p=10, M=200, wc=180,
b=(118,105), dirf=1, Sb=5
a=(118,105), diri=1, Sa=1, K=10, p=5, M=220, wc=140,
b=(189,97), dirf=2, Sb=4

Figure IV.6 Geological lineaments extracted by a semi-automatic approach



a) Lineaments detected by directionnal filtering (Daoust)

b) Lineaments extracted by the semi automatic approach

Figure IV.7

V. APPLICATIONS FOR AN AUTOMATIC LINEAR STRUCTURE EXTRACTION

1.0 INTRODUCTION

The semi-automatic extraction of lineaments and communication networks allow generalization of the method for the automatic extraction of a variety of linear structures.

Using this semi-automatic method, time processing (see table) allows the rapid updating of maps and does not require any prior knowledge.

Application	Mapping Communication Network			Geology Lineaments
Results	IV.2.b	IV.4.d	IV.5.d	IV.7.b
CPU Time (mn)	3	8	3	44

N.B. CPU time is the time required to extract all the structures.

2.0 AN AUTOMATED PROCESS

2.1 Introduction

To extract structures automatically, a two step process is presented in this section.

The first step involves the extraction of network structures using a classic method of morphological process or an edge detecting method. In this network, we will retrieve and characterize structures likely to be used as departure points for linear structure linkage. We suggest some methods to define automatically the location of departure and arrival spots (position and direction), and some criteria to validate the paths.

In the second step, these spots are connected, using the semi-automatic method developed in the former chapter.

2.2 Principle

We attempt to extract communication network (road, rivers, railway lines, etc.) by processing SPOT satellite images, in two steps:

First Step: Primary Detection

This step involves rough network extraction, based on different techniques using classic edge detection operators or mathematical morphology functions. Different methods can be processed

for a low level primary detection (Duda 1973, Vanderburg 1976, Destival 1986, Berthod 1987, Herlin 1988). The object of the next step is to determine the ends of the detected pieces of linear structures. This detection is completed using an automatic linkage.

Second Step: Automatic Linkage

A linkage is processed using the seeking method, optimizing a path in a tree diagram. As the computer knows direction and position characteristics of the end sections, the computer can predict where and how to seek missing information in the gray-level image.

A graph of the original image is run from each end section. This graph seeks a path lengthening the existing sections, with a specific path direction.

The automatic process uses three data files simultaneously:

- image of contours to guide the process,
- ends data file, and
- original image to search for the graph.

2.3 Automatic Linkage Approach Using Punctual Ends

The main problem related to the automation of the semi-automatic algorithm lies in the departure and arrival (position, direction) state detections and the criteria used to stop the process and the criteria used to validate the final path.

The process is applied to a satellite image of New Caledonia

2.3.1 Primary Detection

After tests of different transforms based on basic operators and mathematical morphology, we chose the results obtained by the refined skeleton method (Figure V.2.b). This method involves the use of a threshold based on standard deviation, refined by morphological operators (dilation, skeleton, individual selection). The skeleton image is used to seek punctual ends, as follows:

Each endpoint corresponds to a configuration of a square structuring element that can rotate with a 45° angle.

$$\begin{matrix} 0 & 0 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{matrix}$$

structuring element

As there are four possible directions (according to the representation chosen in Chapter III, Figure III.2), one will attach one direction to every endpoint, after transcoding the direction according to the orientation (i.e. Figure V.1).

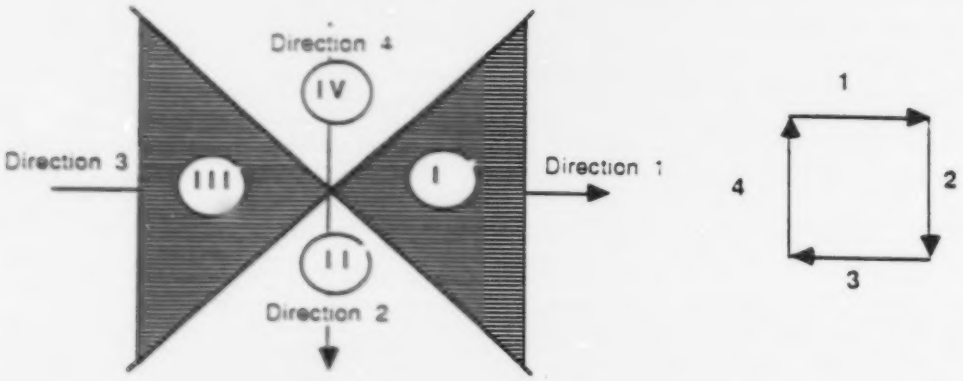


Figure V.1

The seeking direction (direction of the graph route), is a reversal of the end direction.

Angle Zone	Direction of the Endpoint	Direction of the Route
I	1	3
II	2	4
III	3	1
IV	4	2

2.3.2 Automatic Linkage

The results of an automatic linkage, from the skeleton image (Figure V.2.b), using the punctual ends are shown by the following figures:

- original image (Figure V.2.a)
- image of contours (Figure V.2.b)
- "linkage seeking" image (Figure V.2.c)
- result of the automatic linkage superposed on to the original image (Figures V.2.d)

A graph covering the original image is created using all endpoints to look for a path lengthening the existing sections.

The process fails when one of the following conditions are completed:

- the path meets some existing contour elements within a few pixels ($\pm S_b$), or meets the edge of the image.

- the maximal cost (Coût-max) is reached, in order to limit the search so that the program does not look for a wrong track.

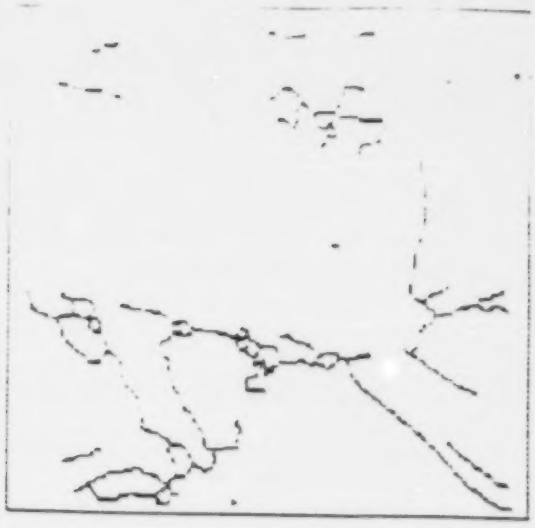
It can be seen that the contour image has been completed by validated contours; however, incorrect detection is easily controlled, due to several factors:

- the departure direction assigned to an endpoint is not significant, if one does not have information on a certain neighbourhood around the endpoint.

- as the search goes on, the graph can meet a validated section, without looking for part of the valid missing section.

In conclusion, the current criteria does not allow the validation of a given path. A good description of the departure stages and more consistent criteria are required. The next section deals with this problem.

a) Original image (New-Caledonia XP)



b) Image of contours

c) "Linkage seeking" image

d)Final network superimposed onto the original

Figure V.2 Network extracted by the automatic approach using endpoints

2.4 Automatic Approach, Using Convex Ends

The major problem of the algorithm is its sensitivity to different departure parameters (position, direction).

In this part we develop an "endpoint seeking" method and new tools such as an overcost function, reversed path, and seeking corridor useful for the seeking control of the final path.

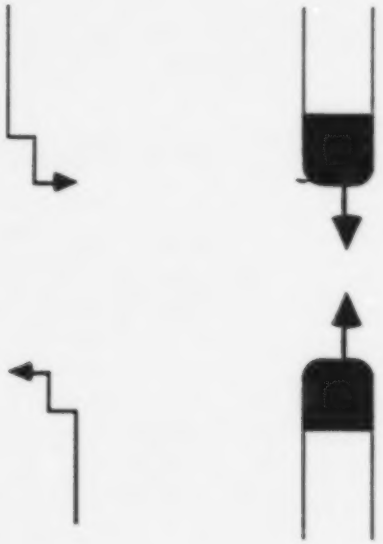


Figure V.3

2.4.1 Primary Detection

For images with low plot density, a standard deviation processing will be enough to highlight a network sketch as in the test image of New Caledonia. For images with a high plot density, standard deviation processing highlights network structures but also plot edges. This is a major problem if the field contours can not be isolated.

We used mathematical morphology functions for these types of images: top hat transform followed by a selection of the longest sections. Structures are eliminated with a length smaller than a given threshold. The image that includes dilated contours will be used later to locate departure endpoints. The dilation is processed in order to thicken structures to obtain convex ends configuration.

Ends Seeking:

We processed an "end-seeking" method on the dilated image of the contours using a seeking automaton; selecting in a view window (size nxn); pixel configurations connected to the central pixel and having a high curviness. Linear configurations, which are not likely to belong to one of the configurations, are rejected.

We then evaluate, for each selected end, some data required for the elaboration of the search (mean angle, seeking direction associated).

The "end seeking" algorithm includes two steps:

Step 1:

A search for a selection of ends configuration.

For each central pixel (different from zero) of the view window (size nxn), we activate a seeking automation of the pixels connected to the central pixel.

The seeking automaton (Figure V.4) processes two windows (size mxm and size (m+2) x (m+2), m = 3,5,7,9,11...), excepted for the first process.

For each pixel, different from zero, located on the edge of the (m+2, m+2) window, one looks for its connected to a pixel of the edge of the (mxm) window (Figure V.5). The pixels connected to the central pixel are memorized in the (m,m) window.

The seeking process repeats itself until m+2 reaches the value n.

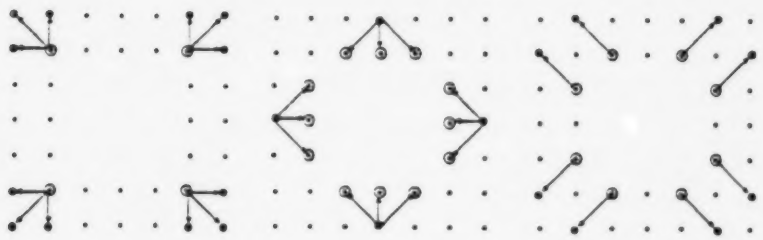


Figure V.4 Seeking automaton

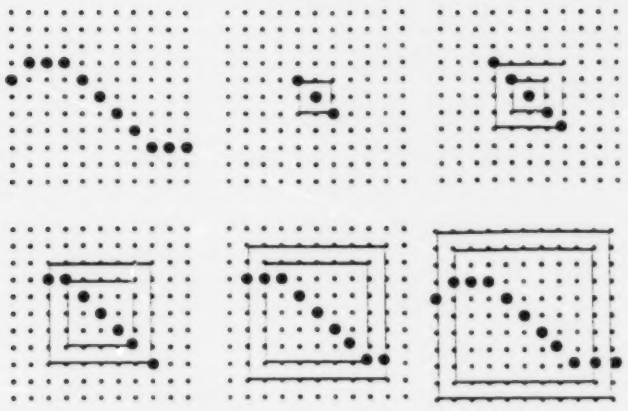


Figure V.5 Example of the search for a configuration

We then select the pixel configurations connected to the central pixel, rejecting linear configurations having a low curviness (i.e. Figure V.6).

Each central pixel is kept if the gravity centre of the connected points configuration is at a longer distance than a given threshold. The local curviness can be measured by the distance of the gravity centre from the window centre. The direction associated to the gravity centre indicates the curviness direction assigned to the central pixel (Figure V.7).

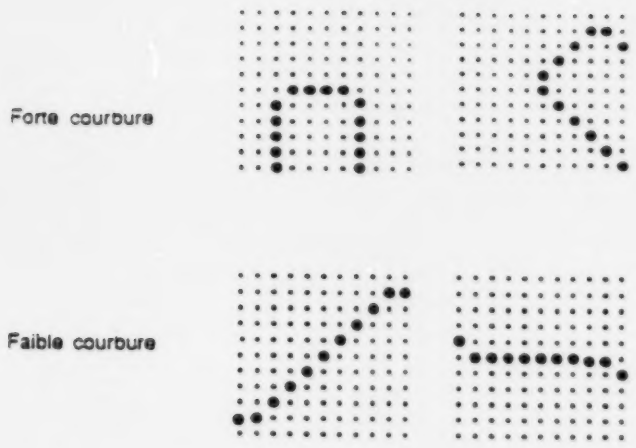


Figure V.6 Examples of configurations

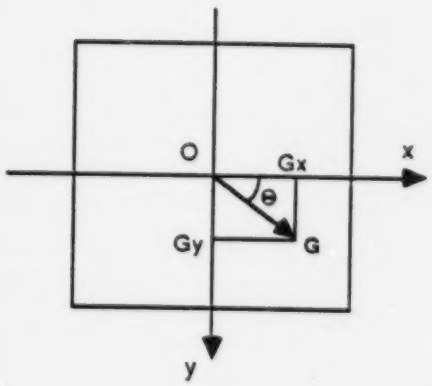


Figure V.7

Scanning the image of the contour, we generate two files. The first includes the filtered image, the second includes a list of the positions and the angles of the remaining points.

Step 2: Orientation Evaluation

The mean angle of every end is calculated from all the points composing the end, and then allocated the corresponding seeking direction.

The transcoding of the end directions is processed according to the mean angle "Θ" (i.e. Figure V.1). The seeking direction (direction of the path route) is the opposite of the end direction (i.e. allocation table, Page 27).

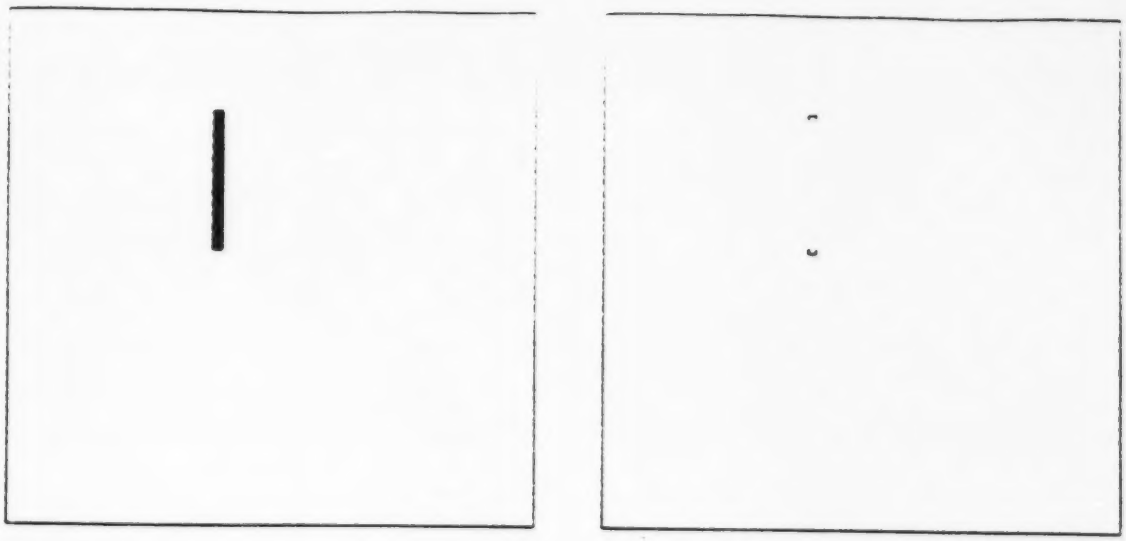
Eventually, all the information derived from the two steps is collected in a data file which includes the following information for each section:

- identification number
- departure mean angle
- departure direction
- reference of the points composing the end section

The following example illustrates the search and selection of endpoints from two different configurations (Figure V.8.c), extracted from the test image (Figure V.8.a). Endpoint masks are shown in Figure V.8.b.

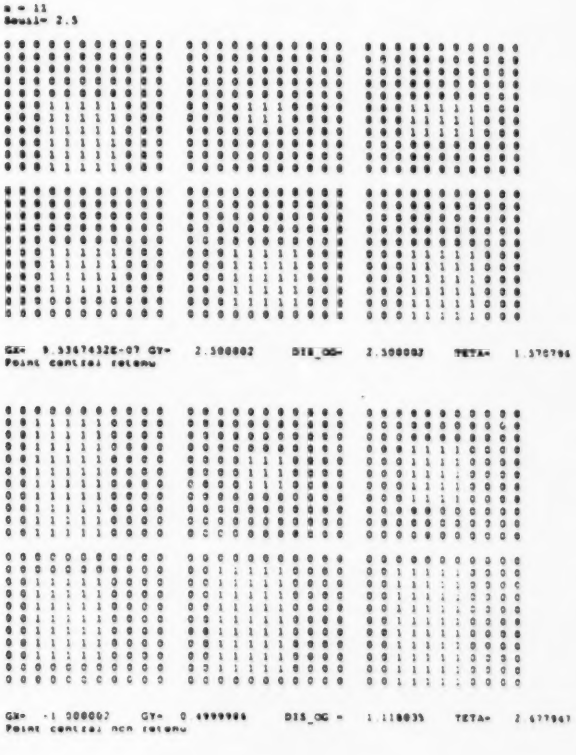
Figure V.8.c gives for each configuration, the seeking sequence of points connected to the central point using the view window, the coordinates, the distance from the origin and the orientation associated with the centre of gravity. Among the two configurations, only the central point of the first one is kept as an endpoint related to a high curviness configuration.

N.B.: In this part, endpoint masks of the different application are made of a 21 x 21 view window and a threshold ranging from 3.5 to 4.



a) Test image

b) Endpoints identified



c) Search and selection of endpoints

Figure V.8

2.4.2 Automatic Linkage

After defining the departure endpoints, the automatic linkage is processed using three data files:

- image of the labelled contour
- endpoints data file (individual number, position, direction, mean angle)
- original image

A graphic scanning the original image is run from each endpoints to search for a path extending the existing sections (different labels) of the contour image. The graph elaboration is completed when one of these two following criteria is achieved:

- One section meets another section with a different label, or the edge of the image.
- The maximum cost is reached. This criteria prevents the process from combinatory explosion (endless processing).

2.4.3 Seeking Control

The critical points required to find a path are time and the number of nodes generated to find the solution. Generally, one cannot look for all the possible paths because nodes increase exponentially. This problem is known as the combinatory explosion.

The graph elaboration requires special attention to avoid combinatory explosion. The use of certain criteria can direct path seeking, reducing the number of nodes that the process has to consider.

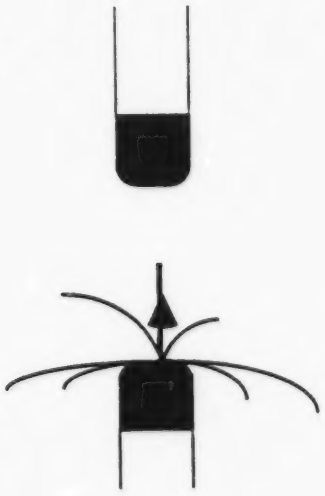


Figure V.9

We have introduced new control elements, such as the overcost function, reversed path and seeking corridor, as new path validation criteria:

1. Overcost Function

The overcost function favours the path seeking in the departure direction of the departure endpoints (i.e. Figure V.9). You then give penalties to the nodes extended in a different direction from the "main direction".

$$C'(x_n) = K_0 \bullet \left(1 - \exp - \frac{||\varphi_n| - |\varphi_0||}{n}\right)$$

where

φ_o: mean angle related to the departure direction
φ_n: angle related to the vector $A(x_o)$ B (x_n), of Figure V.10
K_o: constant

We chose a fast decreasing penalty function (exponential) $C'(x_n)$ that will be added to the global cost defined on Page 14.

This function influences only the beginning of the path and decreases very rapidly towards zero, as it depends on the length of the path (n).

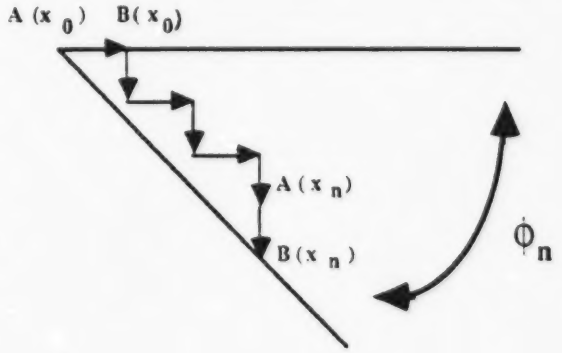


Figure V.10

For a five pixels length or more, this overcost does not have an influence on the overall cost any longer.

2. Reversed Path

The major difficulty in solving the problem is to distinguish the good detections from the bad. If only the first criteria is used, some parasites are highlighted (for instance, field edges).

To solve this problem we seek the reversed path of a direct path, after the direct one has been successful. All the communication network structures (highways, railway lines, roads, rivers,...) are characterized by two edges (i.e. Figure V.11).

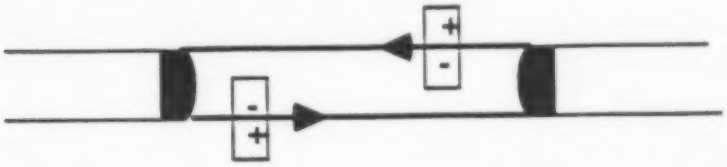


Figure V.11 Direct and reversed paths

The algorithm is run to detect one edge of the structure, and when a different labelled endpoint is met, the algorithm is run in the opposite direction (from a neighbourhood endpoint) to find the other edge of the structure.

3. Seeking Corridor

To speed up the search for the reversed path, we define a seeking corridor defined by the direct path.

Figure V.12 Seeking corridor

4. Performance Measuring

It is impossible to get an efficient algorithm development without using a performance measurement able to control the coherence of the method. The measurement used is called "penetrance" P (Nilsson 1971).

$P = L/T$

with L: length of the path
T: number of nodes explored to find the path

A blind method would lead to a combinatory explosion and to a low value for P.

5. Criteria to Validate the Paths

The information available on both paths (direct and reversed) allows the choosing of criteria appropriate to the seeked structures.

Both direct and reversed paths are kept at the end of the process if the following conditions are fulfilled:

- The arrival point of the reversed path is within a few pixel distance from the departure point of the direct path.
- The number of common points for both paths (direct and reversed) is smaller than a given threshold.
- We introduce the performance criteria based on direct and reversed path. Both paths are kept if:

  a) $|P_o - P_1| \geq$ threshold

  b) $\lambda P_o + (1 - \lambda).P_1 \geq$ threshold $\quad \lambda \in [0;1]$

2.4.4 Applications

Application 1:

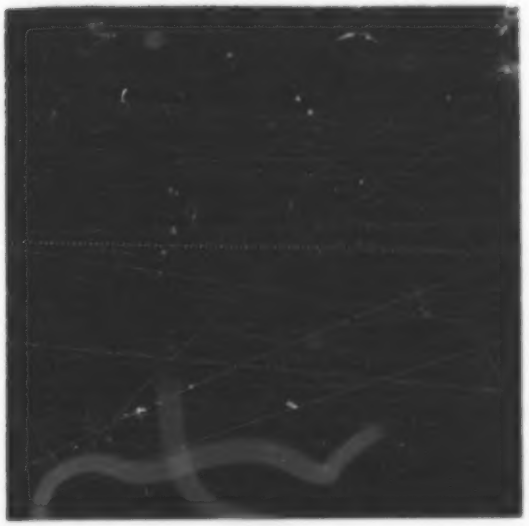
A first application is processed on a 256 x 256 image of New Caledonia, simulation SPOT-XP,

- original image of New Caledonia (XP) (Figure V.13.a)
- communication network outline with departure endpoints (Figure V.13.b)
- "linkage seeking" image (Figure V.13.c)
- result of the automatic process using the performance criteria a superposed on the original image (Figure V.14.a)
- result of the automatic process using the performance criteria "b" superposed on the original image (Figure V.14.b)

The network outline is the result of a standard deviation process followed by morphological transforms (skeleton, individual selection, dilation). The results IV.22.a and IV.22.b were removed from the shortest sections that are not connected to the rest of the network.

The results are encouraging and highlights the efficiency of the algorithm in detecting structures that were missed by other techniques. However, the lower left side of the image is more difficult to process because of the terrain. The same is true for the main road which is partially discontinuous and hard to detect.

The performance criteria seems to be necessary only for images that required strict control. The criteria efficiency is not totally guaranteed, but gives good results in most cases.



a) Original Image (New-Caledonia XP)

Figure V.13

c) "Linkage seeking" image

b) Contoured image with endpoints

Figure V.13

a) Final network superimposed onto the original
(Criteria "a", Threshold=0.02)

b)Final network superimposed onto the original
(Criteria "b", L=0.4, Threshold=0.04)

Figure V.14 Network extracted by the automatic approach, using convexed ends (application 1)

Application 2:

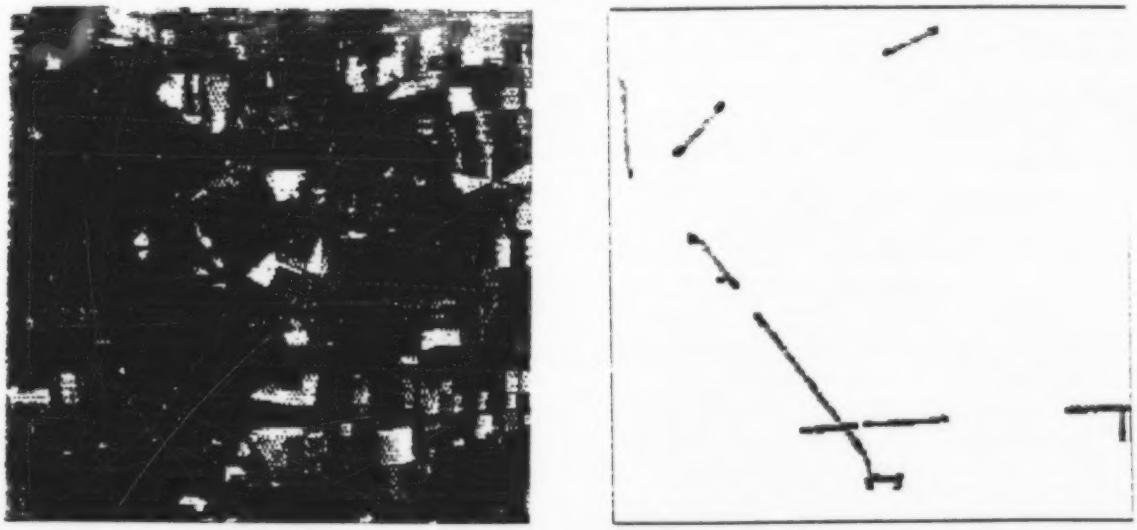
A second application was processed on a 256 x 256 SPOT image (la Rochelle, France, date 30.4.86, XS3-20m, K = 35, J = 257) in the SPOT-image reference system.

The results are displayed by the following figures:

- original image (Figure V.15.a)
- communication network outline with departure endpoints (Figure V.15.b)
- "linkage seeking" image (Figure V.15.c)
- result of the automatic process (Figure V.15.d)
- superposition of the final network on the original image (Figure V.16.a)
- superposition of the skeleton final network on the original image (Figure V.16.b)

The network outline results from a mathematical morphology process (top hat transform followed by a selection of the longest sections).

Note the parallel contours related to direct and reversed paths on Figure V.15.d.



a) Original image (La Rochelle XS3) b) Contoured image with end masks

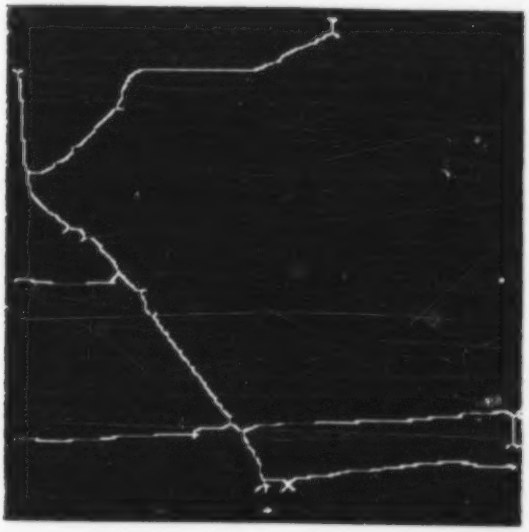
Figure V.15

c) "Linkage seeking" image

d) Automatic linkage
(Without performance criteria)

Figure V.15 Network extracted by the automatic approach (application 2)

a) Final network extracted by the automatic approach, superimposed onto the original



b) Same network skeletonised

Figure V.16

2.5 Conclusion

The automatic process is based on the use of convex ends to seek structures in the image (rather than using simple punctual ends).

Control tasks increase the efficiency of the automated process, including path identifications, even where the structures extracted are not segmented (road, river, railway lines,...)

The results are encouraging, considering the small amount of prior knowledge of the image that is known by the computer.

3.0 CONCLUSION

We have presented applications of graph theory for the detection and following of contours considering two approaches (semi-automatic and automatic).

The semi-automatic approach allows the detection of a network connecting one point to the other; interactively selected and without preprocessing of the image. Generalization of the process allowed automatic obtaining of the entire communication network in two steps. The first step was a primary detection of the outlines, the second step involved an automatic linkage run from the selected section endpoints. An automaton was used to detect endpoints. The seeking progress and the structure validation were improved using new concepts (overcost function, seeking corridor, reversed path).

GENERAL CONCLUSION

Our study has presented results related to linear structure extraction in satellite imagery. The problem is difficult to solve because the seeked structures are just beyond sensor resolutions.

In Chapter II we demonstrated the limits of classic edge detection methods, such as local operator or mathematical morphology functions.

We developed a detection method based on optimizing a path in a tree diagram in Chapter III.

In Chapter IV we presented the tools required to process semi-automatically and automatically satellite images. The iteration of this algorithm on the same image with different parameter values (like M or "wc" for instance) can improve the results of the automated process. This automatic process required very little prior knowledge of the image and could be used as a kernel of a more general system able to do structure segmentation.

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